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Assessment of Shallow Aquifers Contamination by Failure of on-Site Sewage Disposal System in Ughelli, Western Niger Delta, Nigeria

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Abstract
Hydrochemical quality of shallow groundwater aquifers was investigated to assess the potential of contamination by on-site sewage disposal systems in Ughelli. The results are; pH(5.47 – 7.45), Ec (105-483.2µscm), TDS(58.95-294.7mg/l), Na^{+}(1.8-10.95mg/l), K^{+}(2.64-9.87mg/l), Mg^{2+}(2.40-9.89mg/l), Ca^{2+}(3.01-14.90mg/l) and Fe^{2+} (0.02-0.87mg/l). Others include NO_3 (0.04-31.24mg/l), NH_3^{+} (0.015-6.98 mg/l), Cl^{-} (8.5 - 104mg/l), SO_4^{-} (2.24-45.75mg/l), PO_4^{-}(0.21-2.25mg/l). The quality of most groundwater samples from shallow aquifers falls within the tolerance limits stipulated by the WHO and NSDWQ. However, some groundwater samples revealed the presence of high microbial population including total coliform bacteria count (1.78 – 25MNP/100ml) and Escherichia coli (1.35-9.66 MNP/100ml) above the WHO and NSDWQ standards. Interaction between on-site sewage disposal systems and shallow groundwater aquifers was established by the presence of microbial population, high concentration of NH_3^{+} and slightly elevated concentration of NO_3, electrical conductivity and TDS in some the groundwater samples. The extent of contamination of groundwater is strongly influenced by depth of the aquifers, high recharge rate during the wet seasons and availability of permeable soil beneath on-site sewage disposal systems. Consequently the paper recommends that groundwater should be sourced from deeper aquifers and those sourced from shallow aquifer in the area should be disinfected before being used.
Key words; Groundwater, aquifer, coliform, contamination, on-site disposal systems, *WHO and NSDWQ*

Introduction

Groundwater is an important natural water resource which serves as a source of portable drinking water for several millions of people in most parts of Nigeria. The quality of groundwater tends to degrade and also become scarce as the population of any geographical region increases. An increase in population invariably translates into building of more houses, septic tanks for disposal of domestic sewage and more generation of wastes. Septic tank disposal systems are constructed in households for disposal of human wastes. The discharge of sewage into soil overlying groundwater aquifers is often common in Nigeria and many developing countries which lack centralized sewage disposal systems.

The absence of centralized on-site deposal of sewage system for households has made every household to have on-site sewage disposal system for disposal of human wastes emanating from toilets, bathrooms, kitchens and laundries. The effectiveness of on-site sewage system in developing countries is influence by the types of soil and the ability to remove solids from the effluents. Furthermore, in the case of failure, quality of groundwater underneath an on-site sewage disposal system depends to a large extent on the soil types overlying it. The failure of an on- site sewage disposal system affects the quality of groundwater aquifers only when the attenuating capacity of the soil is absent.

According to USEPA (2002), certain urban areas where on–site sewage disposal systems are sited close to shallow aquifers, there is the tendency of interaction of the aquifers with the septic tanks in that area. This is common in karst terrane and in basement rocks (Miller and Ortiz, 2007) and where there is little or absence of soil covering (Miller, 1980). In the Niger delta, groundwater aquifers are prone to contamination by on-site sewage due to the presence of permeable aquifers, high water levels, high hydraulic conductivity and porosity. Thus aquifers of this nature usually enhance the movement of contaminants, not only from septic tanks systems but also from other sources of contaminants downgradients of groundwater flows.

The consumption of water from wells that interacts with an on-site sewage disposal system has some health implications as such has resulted in occurrence of epidemic in certain areas. A relationship between health and quality of water from septic tank that is poorly managed or where high densities of households with septic tanks has already been established by Groundwater Protection Council (2007). The clusters of high densities of septic tank system have been linked to endemic diarrheal illness, and other studies have also demonstrated same relationship between diseases outbreaks and septic tank systems (Craun, 1979, 1984; Bellers et al., 1997 and Borchardt et al., 2003b). Bacteria and viruses which are waterborne can be transported along groundwater flow direction from source points to other areas down gradient of flow. The work of DeBorde et al., (1998) has demonstrated the movement of seeded virus through sandy aquifer for 9 months in the presence of viable seeded virus. Several studies have also shown the susceptibility of shallow water wells to contamination by septic tank systems (Jin et al., 2004; Francy et al., 2004; Gardner and Vogel, 2005; Panno et al., 2007; Landon et al., 2008 and Brown et al., 2009). More also, high contents of nitrate, orthophosphate, chloride, sodium, calcium, potassium, dissolved organic carbon, boron and depleted in dissolved oxygen and depressed in pH in groundwater beneath on-site sewage disposal system have been reported by (Peavy,1978, Robertson et al.,1991 and Panno et al.,2007). Furthermore high concentrations of heavy metals (Fe, Al, Mn and Cr) has been reported by Robertson and Blowes (1995) to develop under anoxic condition in plumes downgradient of on-site sewage system in groundwater beneath on-site disposal sewage system.

In recent times Ughelli has experienced massive expansion and as such, one of the fastest developing urban towns in Delta state. The expansion is adduced to its proximity to Warri; the heart of the hydrocarbon industry in western Niger Delta; availability of affordable accommodation and couple with its strategic location in the heart of western Niger delta. Ughelli and its surrounding environs is host to several oil wells, trunk line, oil fields and flow stations. Consequently, there is rural- urban migration into it, thus increasing the population. Currently, it has over 80,000 houses and about 160,000 septic tanks. Over 80% of the water abstracted from aquifers for use in the 80,000 houses finds its way back to the underlying aquifer from septic tanks. The construction of an on-site sewage system by individuals often lack institutional control and thus quality is compromised, thus susceptible to failure. The lack of inspection to determine the failure of old septic sewage disposal systems is potential source of groundwater contamination. Consequently, the groundwater quality beneath Ughelli is threatened by proliferation of on-site sewage disposal systems emanating from urbanization. This investigation becomes necessary since the extent of groundwater contamination by on-site sewage disposal in the study area is unknown.

Geologic setting

Ughelli is underlain by sequence of the known Niger Delta Formations. The formations from the top to the base are Somebreiro-Warri Deltaic Plain sands, Benin Formation, Agbada Formation and the Akata Formation have been described in details by (Allen, 1965; Reyment, 1965; Short and Stauble, 1967; Weber and Daukuro, 1975). According to Wigwe (1975), the Somebreiro-Warri Deltaic Plain sand is about 120 meters thick and it is Quaternary to Recent. Texturally, the unconsolidated sediments range from fine plastic clay - through- medium-to -coarsed grained sands and rarely gravelly.

The Benin Formation consists predominantly of unconsolidated sand, gravel and occasionally intercalation of shales. It is a freshwater bearing formation in the Niger Delta region and it provides all the freshwater need of the people. Its thickness is about 2000metres and ranges from Oligocene to Pleistocene in age.

The Agbada Formation is the oil bearing formation of the Niger Delta sedimentary basin. It is of Eocene to Oligocene in age. It consists of alternate sand and shale sequence and about 3000 meters thick. The Akata Formation is the basal units of the Niger Delta sedimentary basin and overlies the basement complex. This formation is highly pressured and compositionally it is made up of open marine facies. Its thickness is estimated to be 1000km and the age is from Eocene to Oligocene.

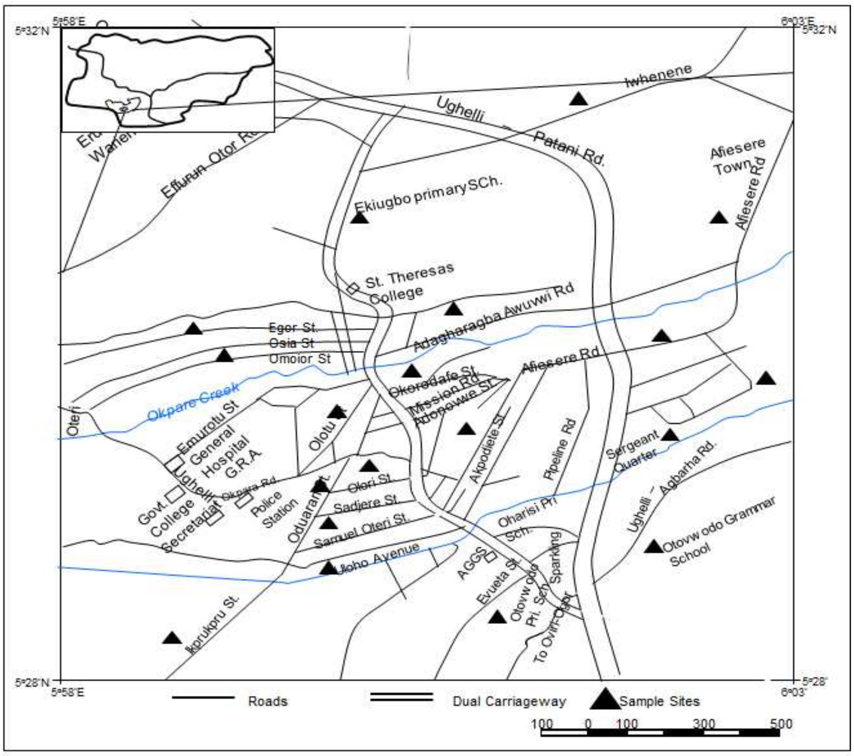

Figure1. Map of the study area showing sample locations

Hydrogeology

The study area consists of unconfined, confined and semi-confined aquifers. They are very productive aquifers, high yielding and characterized by high specific capacities, as well as high recharge rate. The static water level of the aquifers is very high; it often ranges from less than 0.2 to 4meters. The water level fluctuates in accordance with the regimes of the season in a year. It is almost at the ground surface during the wet season and decreased during the dry season. The town is drained by one major river that flows throughout the season and, many streams that are perennial in nature, which flow during the raining season and stagnant in the dry season, these streams are part of wetlands and sometime contribute to the recharge of the aquifers. The aquifers are characterized by grain sizes that range from fine through medium to coarse grained sand.

Geographical setting

The study area is situated in the centrally part of Delta state and located between Latitude $5^{0}28^{1}39.0^{11}$N and $5^{0}58^{1}30^{1}.5^{11}$E and longitude $5^{0}30^{1}53^{11}$N and $6^{0}01^{1}04.5^{11}$ E (Fig 1). It has two climate regimes: the dry season, which spans from November to March; and the wet season which lasts from April to October. The mean annual rainfall is above 2500mm with temperature that ranges from 20^{o}C to 34 ^{o}C; temperatures are usually higher during the day and lower at night. Relative humidity varies between 55% and 75% throughout the year. Vegetation of the area is typical of tropical rain forest region, which have been subjected to suffered quantum deforestation emanating from urbanization, sand dredging, farming and exploration and exploitation of oil and gas activities.

Materials and Methods

Sampling

About 20 samples of water were collected from shallow hand-dug wells in August, 2012. As a principle of precaution sample containers were washed with detergent, rinsed with de-ionized water and rinsed with the sample water prior to collection. Each sample was labeled according to location, preserved at 4^{0}C and transported to the laboratory for analysis. To determine flow direction, coordinates of position of hand- dug wells were taken with portable GPS equipment; water levels and depth to water levels from shallow wells were measured. Surfer -8 was used to plot contours for the depth to water level and water level respectively.

Analytical Method

Laboratory analysis was performed immediately on the samples on arrival at the laboratory in accordance with the American Public Health Association (APHA, 1994) methods. The various physico-chemical parameters analyzed include pH, total dissolved solids (TDS), electrical conductivity (Ec), Sulphates (SO_4^-), chlorides (Cl^-), nitrates (NO_3^-), phosphates(PO_4^-), ammonia(NH_3^+), Sodium(Na^+), Magnesium(Mg^+), Calcium(Ca^+), potassium(K^+). Of the heavy metals only iron (Fe^{2+}) was the analyzed. Results of laboratory analysis were later subjected to descriptive statistical analysis.

Results and Discussion

The results of the physio-chemical analyses and microbial composition of groundwater samples collected from shallow hand-dug wells are summarized in tables 1 and 2. The pH of the groundwater samples analyzed ranged between 5.4 and 7.4, with a mean of 6.7675 ± 0.508971. All pH values are within the standard stipulated by World Health Organization (WHO) and the Nigeria Standard for Drinking Water Quality (NSDWQ) for portable drinking water, except those of Gw3, Gw 4 and Gw 20 (Figure 2), which are below the recommended standards. According to Robertson and Blowes (1995) the concentration of trace inorganics in sewage plume in groundwater may be promoted by pH values below 6.0. Consequently, the very low values of 5.45 and 5.55 recorded for Gw3 and Gw4 may have been caused by leakage from on-site disposal system to the groundwater. The electrical conductivity (EC) values ranged between 105.6 and 483.1us/cm with mean value of 265.0488 ±130.0869, while the Total dissolve solid (TDS) varies from 58.95 to 294.7mg/l, with mean value of 155.3325 ± 71.20815. Both the EC and TDS values are below the permissible limit stipulated by WHO and NSDWQ for portable drinking water (Figure 2).

Human wastes contain sodium (Na^+) and chloride (Cl^-) and they are often disposed in on-site septic systems. Consequently, elevated concentrations of Na^+ and Cl^- in groundwater reflect groundwater which may have been affected by failure of an on-site sewage disposal system (Fig.2). The obtained Cl^- concentrations ranged between 8.5 and 104mg/l, with mean value of 42.2115± 34.32409 and Na^+ ranged between 1.8 and 10.95mg/l and with mean value of 4.4±2.193705. The concentrations of Na^+ ions determined fall below the stipulated standard by WHO and NSDWQ for portable drinking water.

Table 1: Descriptive statistics of the Physico-chemical qualities of groundwater samples analyzed.

Variables n = 20				
Parameters	**Min**	**Max**	**Mean+STD**	**WHO (1996) Recommended standard**
pH	**5.4**	**7.4**	**6.7675 ± 0.508971**	**6.5-8.5**
EC (μs/cm)	**105.6**	**483.1**	**265.0485 ± 130.0869**	
TDS(mg/l)	**58.95**	**294.7**	**155.3325 ± 71.20815**	**500**
Na^+(mg/l)	**1.8**	**10.95**	**4.4 ± 2.193705**	**200**
K^+(mg/l)	**2.64**	**9.87**	**5.85 ± 2.250534**	**12**
Mg^{++}(mg/l)	**2.4**	**9.89**	**5.4375 ± 2.205674**	**50**
Ca^{++}(mg/l)	**3.01**	**14.90**	**7.405 ± 2.894511**	**200**
Fe_2^{++}(mg/l)	**0.02**	**0.87**	**0.276 ± 0.326886**	**0.03**
NO_3^-(mg/l)	**0.04**	**31.24**	**4.981 ± 7,119029**	**50**
NH_3^+(mg/l)	**0.015**	**6.96**	**0.9123 ± 1.599319**	**0.5**
SO_4^-(mg/l)	**2.24**	**45.78**	**16.12 ± 13.99089**	**250**
CL^-(mg/l)	**8.5**	**104**	**42.2115± 34,32409**	**250**
PO_4^-(mg/l)	**0.21**	**2.25**	**0.7985± 2.508791**	**5.0**

Of all the samples of groundwater analyzed, 40 percent has concentrations of Cl^- above the mean value of 42.111mg/l, while 60 percent is below it. Also, 50 percent of the groundwater samples analyzed have concentrations of Na^+ below the mean value of 4.4mg/l and the other above it. The groundwater is regarded as fresh but observed variation in the concentrations of Cl^- and Na^+ did indicate minute level of contamination by on-site sewage disposal systems. The content of K^+ varies from 2.64 to 9.87mg/l and mean value of 5.85mg/l (Table 1). Greater proportion of samples has their concentrations above the mean concentration, which represents 65 percent of the entire samples. The concentration of K^+ is relatively high and close to the limit of 12mg/l stipulated by WHO and NSDWQ for drinking water quality. The spatial distribution in the concentrations of K^+ in the groundwater samples is a clear evidence of the effect of on-site deposal systems failure. The mean content of Mg^+ concentration is 5.4375mg/l and also ranges between 2.4 and 9.89mg/l, 60% of the entire samples have concentration that is below the mean. Furthermore, the concentration of Mg^+ is lower that the allowable limit recommended by WHO and NSDWQ for drinking water quality. The presence of Ca^+ in groundwater is a good indicator of its contamination by sewage. The measured concentration of Ca^+ varies from 3.01 to 14.90mg/l, with a mean of 7.405mg/l. Of all the samples analyzed, 35 % of them have concentration above the mean and 65% lesser than it. These concentrations of Ca^+ however fall below the standard stipulated by WHO and NSDWQ for drinking water quality. It is clear from Table 1 that the concentration of ions of calcium is higher in that order; $Ca^{++} > Na^+ > Mg^{++} > K^+$. The concentration of Fe^{2+} ranges between 0.02 to

0.87mg/l, with mean value of 0.276mg/l. The majority of the groundwater samples (65%) have Fe^{2+} concentrations higher than the 0.03mg/l stipulated by WHO and NSDWQ for drinking water. The high preponderance of Fe^{2+} in the groundwater samples measured is similar to those obtained by Ophori et al., (2007). The source of Fe^{2+} in shallow water aquifer is yet to be ascertained in most parts of the Niger Delta. It is suggested that the preponderance of Fe^{2+}, which characterized some shallow groundwater aquifer, is probably due to leakage from on-site septic disposal systems failure. This suggestion is supported by the results of Chilton et al., (1999), who demonstrated that under anaerobic condition, iron sulphide is usually precipitated from the seepage of sewage through the subsurface underneath failed on-site disposal systems. In addition, Fe^{2+} may have been transported in suspension form weathering of sources rich in iron and subsequently deposited along with clays and sediments in the coastal plains of the Niger Delta. The Fe^{2+} is subsequently released into the porewater when the Eh become negative.

Table2: Statistical summary of Microbial composition of groundwater from shallow aquifer in Ughelli.

n=20 Parameters	**Min**	**Max**	**Mean**	**WHO (1996) Guideline**
Total Coliform	1.78	25	6.5685±7.119734823	0.05 (MNP)/100ml
E.Coli	1.35	9.66	3.7215±3.136275	0(MNP)/100ml

The availability of nitrogen and phosphorus compounds in groundwater is a reflection of contamination by on-site disposal systems (Miller, 1980). Of these compounds, NO_3^-, NH^{3+} and PO_4^- were determined (Fig.2). The results revealed that NO_3^- concentration vary from 0.04 to 31.24mg/l, with mean of 4.981mg/l, 65 and 35 percent of the samples concentrations are lower and higher than the mean concentration respectively. The low concentrations of NO_3^- ions measured in groundwater samples may be attributed to gradual attenuation of NO_3^- due to mixing of recharge water and dispersion in the aquifer (Groundwater and assessment programme, 1999). From the total 20 samples of groundwater analyzed, 60 and 40 percent of the samples have concentration of NH^{3+} lower and higher than the mean of 0.912mg/l respectively. While the concentration of NO_3^- is less than the allowable limits, NH^{3+} is more than WHO and NSDWQ for portable drinking water. The elevated concentration of NH^{3+} in the groundwater above the recommended standard indicates that the quality of groundwater has been affected by on-site disposal systems. Sulphate (SO_4^-) was detected in all samples but in low concentrations, however, all were within the required tolerance limits of WHO and NSDWQ for drinking water (Table.1). The obtained concentration of SO_4^- varies from 2.24 to 45.78mg/l and mean value of 16.12mg/l. 65 percent of the samples have their SO_4^- concentrations below the mean, while 35 percent above the mean. The low concentration of SO_4^- values determined in the study area may be adduced to sulfurization process in the anaerobic groundwater according to Chilton (1999).

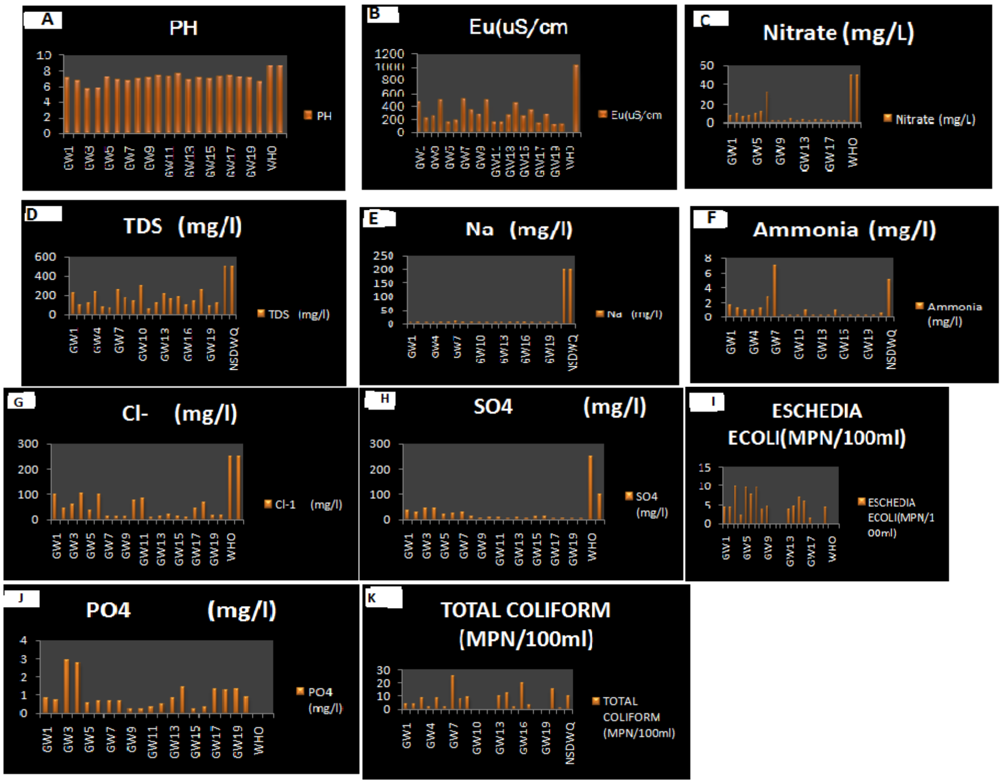

Figure 2: Indicators of septic tank disposal system failure in groundwater (elevated level of A- K in groundwater reflects contamination by sewage system) the presence of F, I, J and K strongly indicate water quality that has been impacted upon by septic tank failure.

Furthermore, phosphate (Po_4^-) has a mean concentration of 0.93mg/l. Of all 20 samples analyzed, 80 percent has concentrations of PO_4^- lower and 20 percent is higher than mean respectively. These concentrations of PO_4^- ions are below the standard stipulated by WHO and NSDWQ drinking water quality. Small amount of PO_4^- as small as to 0.1mg/l in water can leads to the development of slimes and algal growths (Adekunle *et al*., 2007). In a poorly buffered system higher concentration of PO_4^- should be of concerned due its detrimental effects on food preparation (Longe and Balogun, 2009).The low concentrations of PO_4^- ions observed in the groundwater samples was caused by the attenuation of PO_4^- in the unsaturated zones. The Groundwater and assessment program (1999) has shown that low concentration of PO_4^- in urban groundwater is due to attenuation of PO_4^- in the unsaturated zones, which retards its movement into groundwater. Once PO_4^- reached the saturated zones, it cannot be attenuated (Noss and Billa, 1988; Kaplan, 1987).

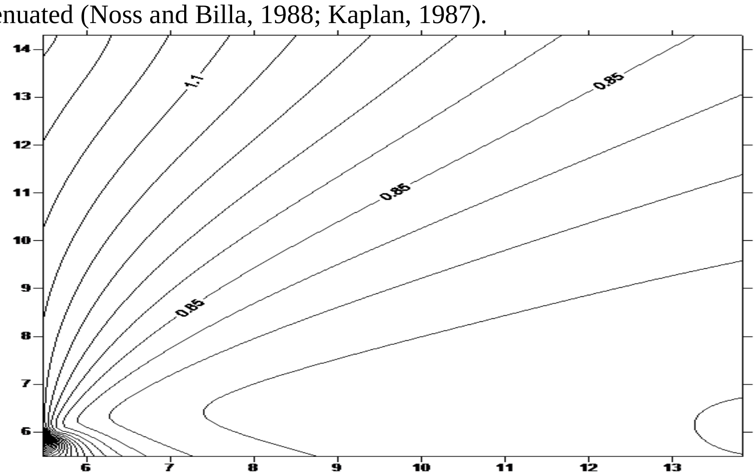

Figure 3: water level contour plot of the study area, water level in some shallow hand-dug wells are less than 1metre especially during the wet season

On-site disposal system is repository for human wastes. Apart from the laundries and bathrooms wastes, there are those generated from the gastrointestinal tracks of humans. The gastrointestinal tracks of human contain bacterial such as Coliforms. The presence of feacal coliforms in groundwater aquifers signifies effluents from on-site disposal systems. The bacterial composition of the groundwater analyzed ranged from not-detected (ND) to 25MNP/100ml and ND to 9.66 for the total coliform counts and *Escherichia coli*, with mean value for 6.5685 and 3.7215MNP/100ml respectively (Table 2). The obtained values for the total coliform counts and *Escherichia coli* in the groundwater samples are significantly higher than the WHO, 1996 guidelines, which indicates that 75 percent of shallow groundwater samples are hydraulically connected to on-site disposal systems and as such not fit for drinking. The observed contaminations of groundwater by pathogens may be attributable to the existence of high water table (Figure 3), flow by-passing the clogging mats, which is common during higher recharge period of the year and the shallowness of the aquifers (Figure 4). When the clogging mat is by-passed by percolation of wastewater from septic tanks, it may results in the introduction of microbes into aquifers (Ground water and assessment program, 1999). The reason for this is that attenuation of pathogens usually takes place at the clogging mats, which is often situated between the soils and the drainfield media.

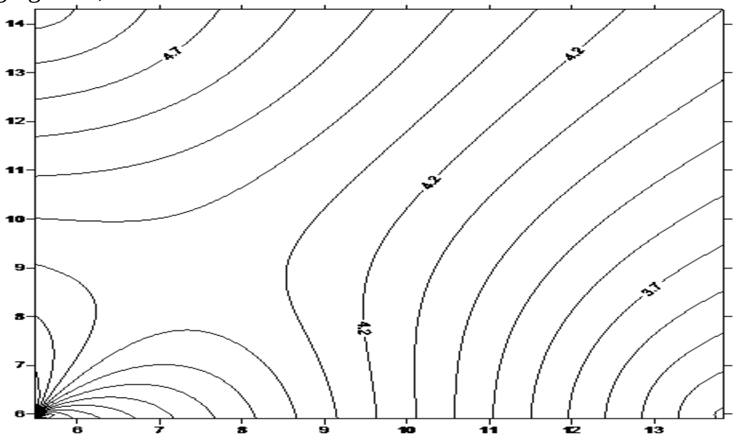

Figure 4: Depth to water level contour

The contribution of soils to the attenuation of contaminants and effluents from on-site disposal systems cannot be overemphasized. They assist in the reduction of effluents from septic tanks by way of absorption, dispersion and retardation of the migration of contaminants within the vadose zone, thereby reducing the degree of groundwater contamination. The characteristics of soils (Figure 5) in the study area may have played significant roles in attenuation of effluents from septic tank disposal systems, thus most of the groundwater samples were not affected by failure of septic tanks.

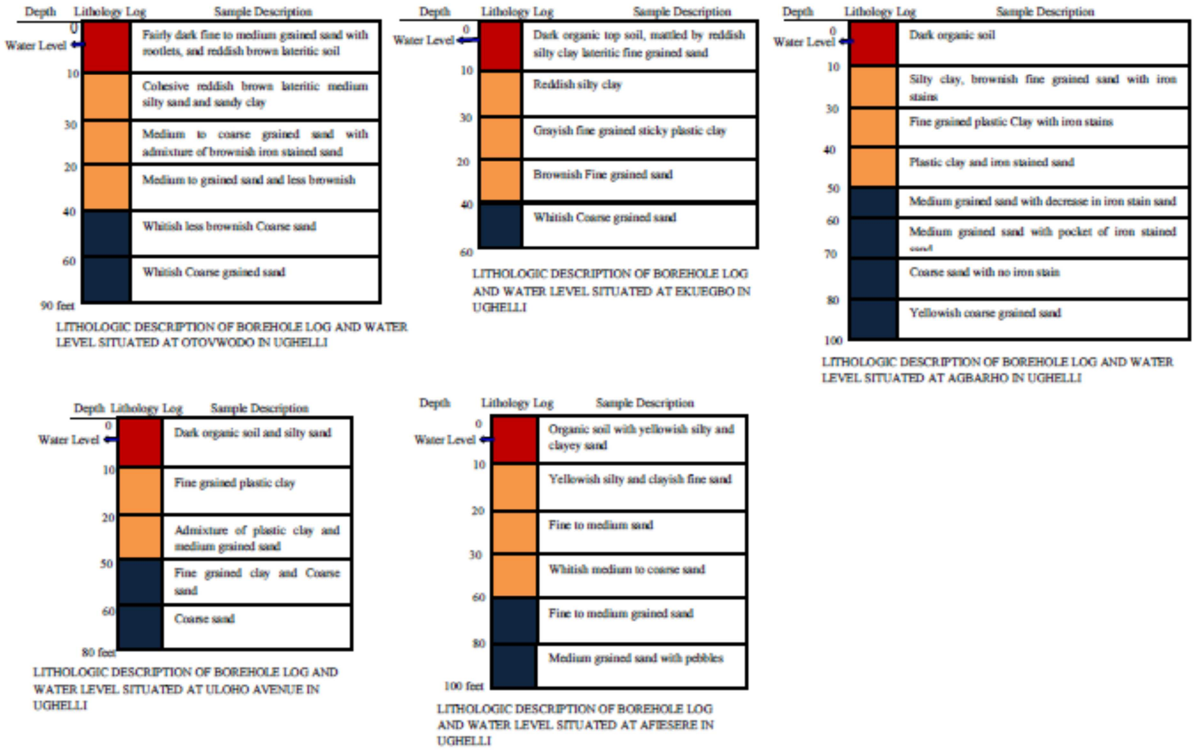

Figure 3; Lithologies description of some boreholes and water levels in study area

Conclusion

The slightly elevated concentration of NO^{-}_{3}, electrical conductivity and TDS, the spatial distribution of other anions and cations and, coupled with strong evidence of the presence of feacal coliform and E-coli as well as concentrations of NH^{3+}that were above the tolerance limit of the standard recommended by WHO and NSDWQ, suggest that the groundwater samples may have been contaminated by on-site sewage disposal systems. Therefore, the hydrogeochemical investigation of shallow groundwater aquifers has demonstrated hydraulic connection between on–site sewage disposal systems and some of the shallow groundwater aquifers in the study area. This is reflected more among the shallowest of the shallow aquifers, which are more hydraulically connected to the on-site sewage disposal system than the deeper shallow aquifers, especially during the wet seasons.

The few contaminations recorded in groundwater samples may have emanated from the inability of soils in the unsaturated zones to attenuate the effluents, as result of the presence of permeable soils below septic tank and high aquifers recharge rate common during the wet seasons. During the wet seasons the clogging mats that usually help in natural attenuation are often by-pass by groundwater percolation. However, the low concentration of anions and cations measured in the hydrogeochemical investigation also shows that naturally attenuation by the unsaturated zone may have contributed significantly in causing the reduction in the measured concentrations, which are below the WHO and NSDWQ standards. The conclusion therefore is that some of the shallow aquifers are not fit for drinking and it is recommended that drinking water in Ughelli area should be sourced from deeper aquifer by drilling rather than hand-dug wells, which are often prone to contamination by effluent from on-site sewage disposal systems as demonstrated in the study.

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